Available online at www.sciencedirect.com

ScienceDirect

Fisheries Research 90 (2008) 17–25

FISHERIES RESEARCH

www.elsevier.com/locate/fishres

# Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua

Tim M. Daw *

*School of Development Studies, University of East Anglia, Norwich NR4 7TJ, UK*

Received 25 February 2007; received in revised form 28 August 2007; accepted 15 September 2007

**Abstract**

Spatial distribution of fishing effort is increasingly recognised as an important consideration for fisheries management, as it can affect trends in catch rates, and be incorporated into planning of spatial management tools like marine protected areas (MPAs). One hundred and ninety-eight household questionnaires provided a coarse indication of effort distribution of artisanal lobster fishers around the Corn Islands, and 32 semi-structured interviews with skippers were used to map individual fishing sites and describe the operating costs and revenues of typical dive and trap-fishing operations. Artisanal fisheries had ranges of up to 50 km, and had moved significantly offshore within the previous 10 years. At the scale of a 5 × 5 min latitude/longitude grid, trap fishing effort was highly aggregated (dispersion coefficient = 3.5), while diving had a regular dispersion (d.c. = 0.1). Descriptions of catch composition at each site showed a clear spatial pattern in the distribution of two locally recognised types of lobster, potentially indicating local stock structures. Economic information was summarised into balance sheets for typical fishers and suggested that fuel accounted for about 52 and 37% of the operating costs of dive and trap fishing captains, respectively. Qualitative questions highlighted trap theft, adoption of geographical positioning system (GPS) technology and fuel costs as major factors affecting spatial behaviour.

The costs and benefits of using more distant grounds were examined by testing for relationships between stated typical catch rates and distance of 90 trap-fishing grounds and between fuel expenditure and catches in 291 daily records of the activities of 3 divers. Maximum catch rates stated by trap fishers were significantly higher at more distant sites and daily catches by divers had a positive relationship with fuel expenditure, which suggested that increasing fuel expenditure to target more distant sites would lead to higher gross revenue as well as higher net revenues, after considering variable operating costs. Thus, there appears to be an economic incentive to extend the range of the fishery. However, fishers may not perceive these positive trends in catch rate with distance due to catch variability, and costs other than fuel, which complicate the trade-off between catch and distance.


*Keywords:* *Palinurus argus*; Fishing effort distribution; Corn Islands; Fisheries economics; Fishers' knowledge

## 1. Introduction

A number of authors have argued for the importance of understanding both spatial (Booth, 2000; Gillis, 2003; Hutchings and Myers, 1994; Wilen et al., 2002) and behavioural aspects (Hilborn et al., 2005; Salas and Gaertner, 2004) of fisheries. The resurgence of interest in spatially explicit management measures, including marine protected areas (MPAs), highlights the relevance of spatial distribution of fishing effort to fisheries management (Moustakas et al., 2006; Walters, 2000). For example, the interpretation of trends in catch-per-unit-effort (CPUE) should take account of changes in the spatial distribution of fishing effort (Gobert and Stanisière, 1997; Jennings et al., 2001; Koslow et al., 1994; Walters, 2003).

Spatial effort distribution is the result of individual fishers' behaviour, which is in turn affected by various factors, some of which are highlighted here. Spatial patterns of targeted resources and habitats affect effort distribution in as far as fishers are able to perceive them (Pet-Soede et al., 2001). Fishers may maximise such knowledge by preferring familiar grounds where they can accumulate detailed local knowledge (Begossi, 2001; Rijnsdorp et al., 1998). Technical considerations may determine potential fishing areas, for example, depth limits for free-diving or smooth ground for trawling (Bene and Tewfik, 2001; Rijnsdorp et al., 1998), while technical innovations may allow more accurate navigation or monitoring of trends in catch data (Eales and

* Tel.: +44 191 222 5048; fax: +44 191 222 7891.
*E-mail address:* t.m.daw@ncl.ac.uk.

0165-7836/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2007.09.027

Wilen, 1986). Social factors affecting effort distribution may include the activities of other fishers leading to interference competition (Gillis and Frank, 2001) and the existence of rules and institutions. Rules may be formal, like the establishment of MPAs, or informal territorial arrangements established, enforced and monitored by fishers themselves (de Castro and Begossi, 1995; Schlager and Ostrom, 1992).

Various factors interact to determine the distance travelled to sites. Safely navigable distance varies with weather, individual risk aversion and vessel type, and determines the potential resource spaces for different fishers (Pet-Soede et al., 2001). Energy and travel-time costs increase linearly with distance travelled and are determined by fuel expenses and the opportunity cost of time, which depends on other potential activities, for example, fishing at nearer sites or engaging in non-fishing activities. A "friction-of-distance" conceptual approach incorporates various distance related costs and predicts that evenly distributed resources will be exploited more intensively at sites nearer home ports (Caddy and Carocci, 1999). More distant sites would therefore be expected to have more pristine stocks and (according to basic catch/effort models of fisheries) potentially yield higher catch rates. If such a positive distance–catch rate relationship is perceived by fishers, the choice of how far to travel involves a trade-off between the costs and expected higher yields.

In order to understand these patterns and predict the effect of proposed management strategies one must understand the social, microeconomic and natural environment in which fishers make decisions (Aswani, 1998). Wilen (2004) highlights a lack of models which can incorporate the complex ecological and biological feedbacks to realistically predict fishers' spatial behaviour and suggests that more ethnographic research may be necessary to describe fishers' spatial decision making.

In this study, a combination of rapid household questionnaires, mapping, economic analysis and qualitative stakeholder interviews were used to gain an understanding of how artisanal lobster fishers of the Corn Islands perceive and utilise the spaces of the sea around them. The objectives were to (a) describe the spatial distribution of diver and trap-fishing effort; (b) highlight factors determining distance travelled and (c) investigate costs and benefits of distance quantitatively in terms of catch rates and fuel cost.

## 2. Study area

The Corn Islands lie in the Nicaraguan sector of Caribbean Sea on the most extensive portion of the Central American continental shelf. Thus, there is no natural limit to shallow fishing grounds imposed by bathymetry. The two islands are separated by about 15 km, Great Corn Island has the highest population density on the Atlantic coast of Nicaragua, with a population of 7100 residing in 10.3 km$^2$, while Lesser Corn Island, at about 5 km$^2$, is much less densely populated by about 1100 people (Ryan et al., 1998).

A profitable export fishery for the lobster *Palinurus argus* began in the 1970s and became the mainstay of the local economy in the 1980s (Ryan et al., 1998). SCUBA diving for lobster has gradually been replaced by trap fishing due to safety and environmental concerns. In 2003, diving was predominantly practised by the Miskito ethnic group while most Creole fishers (and all fishers on Little Corn Island) used traps. Finfish were also fished commercially although their relatively low price led to considerably more emphasis on lobster. Commercial artisanal fishers generally operated from fibreglass or wooden skiffs 7–10 m long, powered by 40–75 hp outboard engines and crewed by 3–4 fishers. Fishers sold catches to one of 13 middlemen who passed on the catch to one of the two Corn Island based companies for processing and export. The middlemen also provided fishers with fuel, dive cylinders and credit on traps, boats and engines.

Official statistics indicate declining catch rates across the Nicaraguan shelf in the 1990s (Adpesca, 2003). In response, a closed season on fishing lobster was imposed during May and June in 2002 and 2003 and extended to 4 months in 2004. Local regulations also excluded commercial fishing from within two nautical miles of the Corn Islands but lobster divers were known to still fish in this area (Pers. Comm., Corn Island Municipality).

Although *P. argus* was the only species targeted, local fishers clearly distinguished "red" and "white" lobster through physical and behavioural characteristics. In addition to colour differences, red or "stationary" lobsters were generally heavier, more likely to have eggs and found in moderate numbers around the Corn Islands throughout the year in rocky habitat. White or "running" lobsters were caught in large numbers on seagrass or gravel substrates from November to January as they passed through the area from the North (Pers. Comm., various Corn Island fishers).

## 3. Methods

### 3.1. Data collection interviews

Two types of interviews were used to collect information on fishing techniques, costs and fishing grounds in May and June 2003. Firstly, a rapid household questionnaire was administered to a random sample of 198 fishing households stratified by community (Table 1). This gave a large-sample overview of fishing activity and a coarse indication of effort distribution by the different gears. In-depth semi-structured interviews conducted opportunistically with 32 lobster fishing captains then allowed more specific mapping of individual fishing areas (Table 1). The household questionnaire included questions on occupations, species targeted, gears used and boat characteristics, and a simple map of Corn Island in which the surrounding sea was divided into 24 zones related to distance and direction from the islands (Fig. 1). Interviewees were asked to identify which of these zones they used for each fishing activity.

In-depth interviews with boat captains covered equipment used, how they selected fishing grounds, and locations of individual fishing areas. A flexible approach to mapping fishing grounds was required due to differences in navigational equipment, willingness to cooperate and understanding of maps. When possible, the position of each ground was determined by positions from the fishers' own geographical positioning system (GPS) unit recorded to the nearest minute of latitude and longitude. In other cases, locations were determined by direction and the

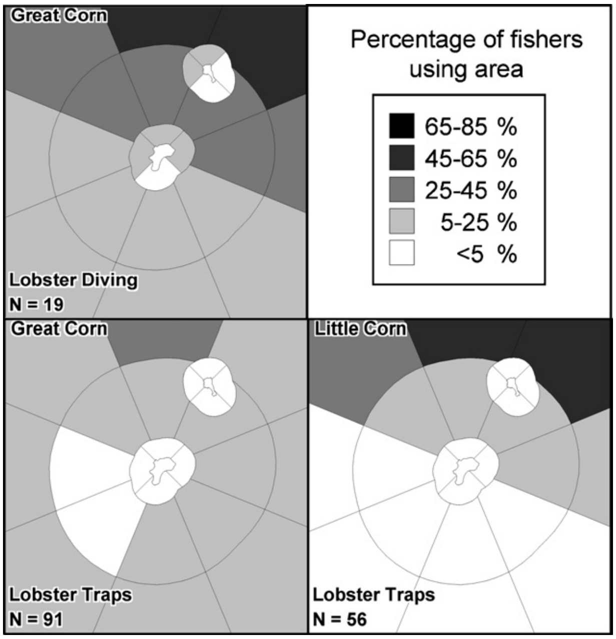


Fig. 1. Percentage use of zones around the Corn Islands by different types of lobster fishers from the two islands.

approximate distance in 'miles' (assumed to be statute miles) or travel time. Interviewees also provided some or all of the following information about each ground: approximate size and shape, local names, typical good, poor and average catch rates, time and fuel to reach, frequency and intensity of use, substrate types, depths and the typical proportion of "white lobster" caught. Depending on the length of time captains had been operating, they were asked their memories of normal, maximum and minimum distances travelled to conduct fishing now, 10 years ago, during the 1980s and during the 1970s. Information was also collected on costs of equipment, maintenance, licences, bait, fuel, tank hire (for divers) and payment to sailors. Data were organised into a hierarchical Access database, linked to a MapInfo geographical information system (GIS).

### 3.2. Mapping fishing locations

Twelve non-specific responses (e.g. "everywhere" or "all around") were removed from the household questionnaires. The proportion of each type of fisher from each island using each of the 24 zones was calculated and plotted using MapInfo GIS software.

In-depth interviews with 26 trap fishermen provided 73 locations and descriptions of fishing grounds and interviews with 7 divers provided 96. GPS positions from interviews were imported directly to MapInfo, while distances and directions were used to estimate the position of grounds in relation to a base map of the islands. Fishers who had a clear line of sight from their home beach to the ground and fishers who used GPS, were assumed to cite distances and directions directly from their home port, as they would be able to read this from the GPS display. Fishers who fished on other sides of the island from their beach and who navigated by transits (alignment of features on land) or compass bearings were assumed to state distance and direction from the point on the island when the first clear line of sight to the grounds was available. These assumptions are the most plausible interpretation of the directions recorded. Given the dimensions of Great Corn, if this assumption is incorrect it would introduce an error in site positions of up to 1.5 km.

Interviews indicated that trap grounds extended for about a 1 mile radius around each position so the number of traps reported for each ground were assumed to be evenly distributed in a 1 mile buffer around each trap location mapped. Distribution of effort across diving grounds was determined by giving each an "attendance index" calculated as the inverse of the number of sites mapped by each diver (assuming that an equal proportion of time was spent at each). The sum of traps deployed and attendance indices were aggregated over a $5 \times 5$ min latitude/longitude grid to protect the exact location of fishing spots (Maurstad, 2002) while indicating general trends. The coefficient of dispersion (variance/mean, Begon et al., 1996) between those grid squares which included fishing was calculated to categorise the type of distribution.

### 3.3. Changes in distances to fishing grounds

The normal, maximum and minimum distances travelled to fishing grounds according to captains were analysed as three separate variables. Two-way ANOVA without replication was used to test each variable in turn for changes in time, with interviewee as a random factor and time-period ("now", "10 years ago", "the 1980s" and "the 1970s") as a fixed treatment effect (Sokal and Rohlf, 1981). This analysis was repeated excluding any observations detected with high residuals (1–3 observations) to check that they did not change the inference of the test. Pairs of time-periods were tested by paired *t*-tests with a Bonferroni correction to account for the six tests possible between four time-periods. A conservative probability of 0.0083 (i.e. 5% divided by 6) was therefore used to test the significance of results (Devore and Peck, 1986).

### 3.4. Microeconomics of fishers

Expenses and prices from interviews with fishers and middlemen were used to compile a balance sheet of a generalised trap fisher and lobster diver in 2003. To simplify capital costs (which were complicated by highly variable credit arrangements with middlemen) they were simply calculated as depreciation plus mean interest as follows:

$$C = \left(\frac{V}{l}\right) + \frac{1}{2}Vi$$

where $C$ is the capital cost of an item, $V$ is the new price, $l$ is the useful lifetime and $i$ is the interest rate (5% was used[1]). Balance sheets were used to calculate the percentage of costs attributable

[1] Some middlemen do not overtly charge interest but lend in US dollars and pay for lobsters in Nicaraguan cordobas. From the fishers perspective this leads to an effective interest rate as the Cordoba has declined at a rate of 0.767 C$ per year since January 2002 (www.xe.com/ict), which is roughly equivalent to 5%.

to fuel for each fishery and the net income gained per pound of catch.

### 3.5. Evaluation of distance–catch rate relationships

Two separate evaluations were made of distance–catch rate relationships; one from interviews with trap fishing skippers and one from records of catch and fuel expenditure of divers. Twenty trap-fishing captains gave estimates of good, poor and/or normal catches per trip at each of 57 sites. These were converted to CPUE according to the number of traps used at each site. Catch rate and distance were square-root transformed to reduce the effect of outliers and allow regression assuming normal error distribution (Zuur et al., 2007) and regressed to test whether CPUE was higher at sites further from the islands.

Records of catches landed and fuel used by three lobster divers on 291 fishing days between July and December 2002 were obtained from one middleman and records of historic fuel, lobster and fish prices were obtained from the records of one of the processing companies. Square-root transformed expenditure on fuel was used as a proxy for distance travelled and was regressed against square-root transformed daily catches of lobster. Changes in fuel price were not accounted for as they only fluctuated by 12% during this period (Central American Fisheries, unpublished data). One to five days were removed from the data on each fisher due to large residuals that had a strong influence on the regression. Removal of these points had no effect on the significance of the regression and gave coefficients more indicative of typical conditions. The resultant regression equations were used along with the generalised diver balance sheet to evaluate the predicted increase in gross and net revenues for a US$ 6.67 (100 Nicaraguan Cordoba) further expenditure on fuel on top of typical levels of expenditure (US$ 16.7 and US$ 30).

## 4. Results

### 4.1. Spatial distribution of fishing effort

Household surveys indicated that the northern zone beyond 10 miles of the island was used by the highest proportion of all types of fishers from both islands (Fig. 1). No Little Corn fishers used grounds south or west of Great Corn but over 30% of Great Corn fishers utilised areas North of Little Corn suggesting that these were favourable grounds. Divers used a wider range of areas than trap fishers, with more usage of southern zones. Few commercial fishers used the zone within 2 miles of the islands and only 5–15% of divers admitted to using any of these nearshore zones.

Plotting of trap fishing grounds reinforced the importance of northern and eastern grounds for trap fishers indicated by the household survey, and allowed patterns to be seen at a higher resolution (Fig. 2A). Trap grounds extended up to 50 km from Little Corn but the highest concentration of effort is seen 10–20 km east of Little Corn. The dispersion coefficient of trap density between 5 min grid squares was 3.47 indicating a highly aggregated distribution of effort. Plotting diving sites and attendance indices per grid square showed individual divers ranging over a wide area in contrast to trap fishers (Fig. 2B) who fished only 1–4 different grounds each. The dispersion coefficient of total

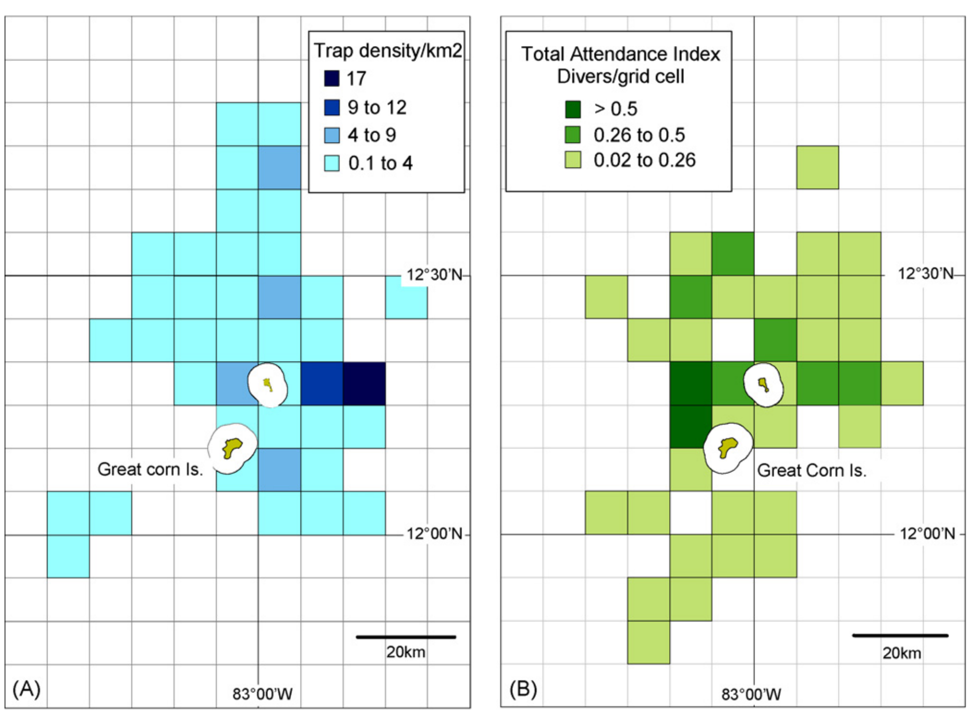


Fig. 2. Lobster fishing effort intensity from in-depth interviews with skippers per 5 × 5 min latitude/longitude grid. (A) Trap density as a result of fishing by 12 Little Corn Island and 14 Great Corn Island trap fishers. One grid square contained markedly higher density of 17 traps/km$^2$. (B) Lobster diver attendance by seven Great Corn Island divers. Attendance indices assume divers spread effort evenly between their own sites.

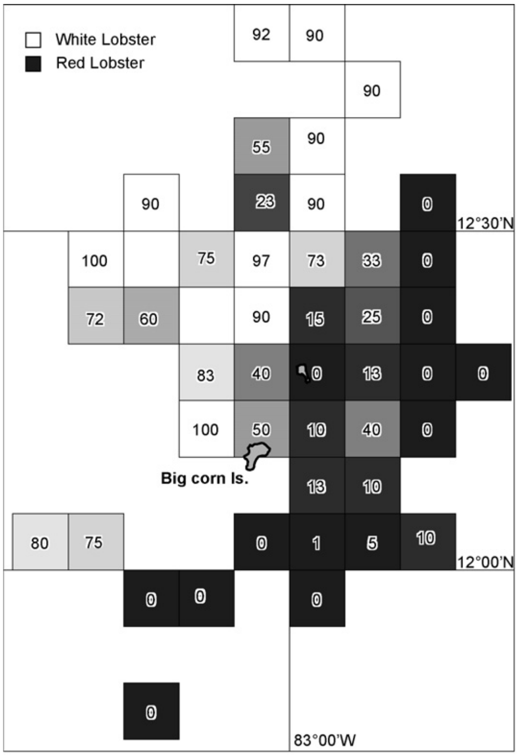


Fig. 3. Relative distribution of red and white lobsters on the lobster fishing grounds around the Corn Islands. Shaded boxes and numbers indicate mean percentage white lobster reported for grounds in each 5 × 5 min latitude/longitude grid square.

attendance index was greatly less than 1 (0.10) indicating a regular distribution.

Interviews showed a clear distinction between the types of lobsters caught by area. Red lobster was reported to dominate catches at grounds in the east and south of the islands, while sites north and west were dominated by catches of white lobster (Fig. 3).

### 4.2. Factors affecting spatial effort distribution

Factors affecting spatial effort distribution and fishing strategies varied between sectors. Trap fishers tended to keep to their individual grounds but move their strings of 2–10 pots between 10 m and 1/2 mile at each setting in response to patterns of catches. Divers had knowledge of many locations and would try them in turn guided by previous experience. Some divers claimed to rotate sites to allow stocks to recover and/or to avoid repeated deep diving. Immediately after the closed season and during strong northerly winds, divers targeted concentrations of lobster close to the islands. After 2 or 3 days of fishing here, catches declined due to harvesting and the lobsters moving back to deep water. Navigational tools used by fishers included landmarks, sea direction, compasses and GPS. Sixty-one percent ($n = 28$) of fishers used GPS, which they had acquired since 1992 (mean 1998). This allowed them to fish farther and in more challenging conditions, save time and fuel by easily locating grounds, and to mark traps with discrete buoys rather than flags to reduce the risk of theft. Fishers reported increased trap theft in recent years and that it was a serious concern, impelling them to fish farther offshore. Eighty-nine percent captains ($n = 9$) stated that they would travel further if fuel was cheaper indicating that they were limited by fuel cost. In contrast, only 43% ($n = 7$) said they would travel further if they had a faster boat suggesting time was only limiting for some fishers.

Captains were not in agreement as to whether better catches could be obtained by travelling further. Although lightly or un-fished grounds were preferred, seasonal rather than spatial variations were more apparent to fishers. Some trap fishers claimed the potential advantages of travelling to more distant grounds were offset by increased conflicts with the industrial fleet, which apparently encroached into the 26 mile zone reserved for artisanal fishers.

### 4.3. Changes distance fished in recent history

Trap captains reported highly significant differences in the maximum, normal and minimum distances ($p = 0.000$, $p = 0.000$ and $p = 0.009$, respectively) travelled to fishing grounds during different periods since the 1970s. All three distances had increased with time, especially during the last 10 years (Fig. 4). Maximum and normal distances were significantly different between now and 10 years ago ($p = 0.006$ and $p = 0.007$, respectively) but not between 10 years ago and the 1980s once the Bonferroni correction is applied ($p = 0.009$ and $p = 0.043$). The mean extension of normal fishing distance from 10 years ago to now was 10.8 ± 6.3 miles (95% c.i.) while maximum distance increased by 10.4 ± 6.9 miles.

### 4.4. Microeconomics of fishing operations

Balance sheets based on a typical profile of lobster and trap operations estimated that fuel accounted for 52% of a lobster diving operation's total costs and 37% of costs of a lobster trap operation (see Supplementary data).

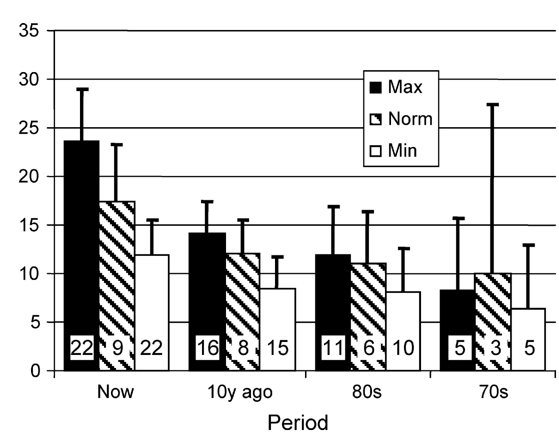


Fig. 4. "Maximum", "minimum" and "normal" distances of fishing sites from home quoted by Corn Island lobster trap fishermen for the past 35 years. Bars indicate mean response ± S.E. Number of responses indicated on each bar.

Table 1
Distribution of sample of fishers by home island, ethnic group and fishing gear

| | Total | Island | | Ethnic group | | | Main fishing gear | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Great Corn | Little Corn | Miskito | Creole and Garifuna | Mestizo | Traps | Diving | Handline |
| Approximate number of fishers[a] | 1700 | 1290 | 430 | 306 | 1230 | 151 | 560 | 80 | 460 |
| Household interviews | 198 | 139 | 59 | 43 | 129 | 22 | 152 | 38 | 5 |
| Fishing areas questions | 196 | 158 | 38 | 91 | 104 | 1 | 60 | 115 | 21 |
| In depth interviews and mapping | 33 | 24 | 16 | 7 | 26 | 0 | 25 | 7 | 1 |
| Information on costs | 16 | 8 | 8 | 4 | 12 | 0 | 11 | 3 | 0 |

[a] Calculated by multiplying government figures from Adpesca (2003) up to total fishing population estimate of 1700.

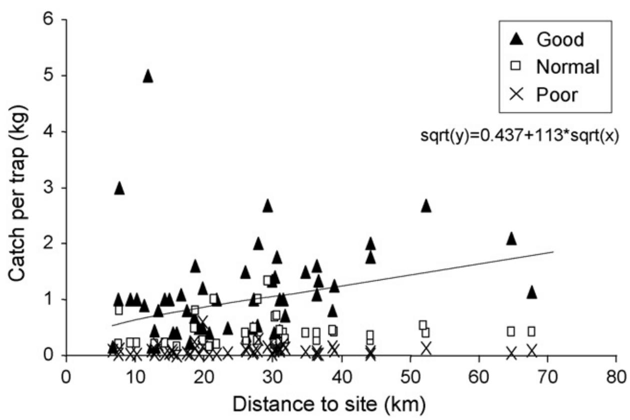


Fig. 5. 'Good', 'normal' and 'poor' catch rates reported by skippers at individual sites plotted against distance from skippers' home island. The regression line and equation is shown for good catches, for which there was a significant relationship.

### 4.5. *Evidence for catch rate–distance relationships*

There was a significant positive relationship between maximum CPUE of trap grounds, as indicated by statements of "good catch" by trap fishers, and the distance of a site from the fishers home island and Great Corn Island ($p = 0.001$; Fig. 5). "Normal" and "bad" catches were not significantly correlated with distance ($p = 0.232$ and $p = 0.562$, respectively).

Despite large variations in catches, there was a significant positive relationship between expenditure on fuel and total weight of lobster caught for each of the three lobster divers examined (Fig. 6 and Table 2). The marginal increase in daily gross margin predicted for a US$ 6.67 (100 Nicaraguan Cordobas) increase in fuel expenditure was US$ 11–18.67 in terms of catch value and US$ 9.47–16.13 on daily margins for the boat captain after covering costs, payments to the diver and assistant and deductions for water weight and tax.

Table 2
Regression relationships found between daily expenditure on fuel and weight of catch for three Corn Island lobster divers between July and December 2002 (equations in the form: $\sqrt{\text{catch}} = a \times \sqrt{\text{fuel expenditure}} + B$)

| Diver | *n* | Gradient (*a*) | Intercept (*B*) | Significance |
|---|---|---|---|---|
| 1 | 94 (2 removed) | 0.0740 | 2.18 | $p = 0.010$ |
| 2 | 96 (5 removed) | 0.0911 | 3.00 | $p = 0.012$ |
| 3 | 101 (1 removed) | 0.1113 | 1.42 | $p < 0.001$ |

## 5. Discussion

This study contributes to a growing literature demonstrating that some understanding of fishing effort distribution can be obtained by a low-tech and cost effective strategy of interviews (e.g. Hall and Close, 2007). The positions of fishing grounds may be subject to errors from misjudgement or misinformation from interviewees, ambiguous use of statute and nautical miles and the generalisation of potentially large, irregularly shaped grounds by the plotting of single positions. However, the accuracy is sufficient to show general patterns of effort distribution with a coarse 5 × 5 min grid. Such effort maps are useful for management by highlighting areas of potential conflict and heavy use, suggesting implications of proposed spatial management measures and indicating biological information about stocks. Accuracy of the patterns observed could be tested and improved by involving more fishers, checking positions at sea while observing fishing activities and by using bathymetric charts and habitat maps to "contextually edit" fishing grounds.

There appeared to be some spatial segregation of the two fishing gears. Thirty-five and 40 grid squares, respectively, contained divers and trap fishing activity but only 15 contained both. This may be due to different ideal habitats for the two fishing methods or the result of conflict which is felt between the two groups (Hume et al., 2005). Informal property-rights or territoriality, which have been shown to regulate fishing areas in other studies (de Castro and Begossi, 1995; Schlager and Ostrom, 1992) were not indicated by open-ended questions during these interviews. However, these may be difficult to elucidate without focussed study so their existence and effect on effort distribution cannot be ruled out.

The distinction between white and red lobster has no biological or taxonomic basis but the widely held recognition of the forms by the islanders and the clear spatial distribution trends uncovered in this study warrant further investigation. Previous studies have shown how such local classifications and mapping of local knowledge can be used to uncover the distribution of species and identify discrete stock structures with implications for management (Ames, 2004; Wroblewski, 2000).

Most studies of fishing effort distribution find aggregated dispersion (Jennings et al., 1999; Pet-Soede et al., 2001) as with that shown by the trap densities in this study. The regular pattern of dispersion observed for divers is therefore unexpected and usually emerges when organisms repel each other or establish territories leading them to space out evenly (Begon et al., 1996). Although fishermen have been reported to have territories (Acheson, 1975; de Castro and Begossi, 1995) examples usually concern fixed gears and territoriality between divers who use sites intermittently seems unlikely. One diver described how he usually spent half of his time at one site, almost half at his next three most popular and only made occasional visits to others. This level of detail was not available for most divers, necessitating the assumption that a diver spreads effort evenly between his sites. Temporal distribution of diver effort between sites could be found through a logbook study as was conducted with artisanal fishers in Kenya (Obura, 2001) and would be expected to increase the variance and thus the dispersion coefficient of diver effort. In addition perceptions of dispersion patterns are determined by the scale at which they are examined (Levin, 1992). If divers focus on smaller grounds (e.g. individual rocks) than trap fishers, examination on a smaller spatial scale than the 5 × 5 min grid used here may have shown a more aggregated distribution.

The historic extension of fishing ranges observed in these fisheries is a typical phenomenon of fisheries as they become overexploited in nearshore grounds (Caddy and Carocci, 1999). Extension of ranges per se does not indicate overexploitation, as it can be due to changes in any factors affecting distance costs. For example, technological improvement (e.g. GPS) can allow fishing at greater distances while trap fishers were impelled to travel further to avoid theft of traps. However, in the case of Corn Island, declining CPUE trends are coupled with an increase in the maximum range from 14 to 24 miles over 10 years (Fig. 4) which would result in a doubling of the potential resource space available to fishers. Area fished is important in the interpretation of CPUE trends (Gobert and Stanisière, 1997; Jennings et al., 2001; Koslow et al., 1994) so when increasing fishing areas is accounted for in Corn Islands, the long-term declines of lobster stocks around Corn Island may be more severe than perceived by fishers or CPUE statistics. Given that extension of ranges is likely to occur in developing fisheries, detection of catch trends by fishers or managers may be hidden by CPUE ‘hyperstability’ (Hilborn and Walters, 1992) if range extension buffers CPUE from declines in stocks. It is therefore important that fisheries managers are aware of trends in spatial effort distribution.

There was evidence that catch rates were higher at more distant sites in both the trap and dive fishery. The significant

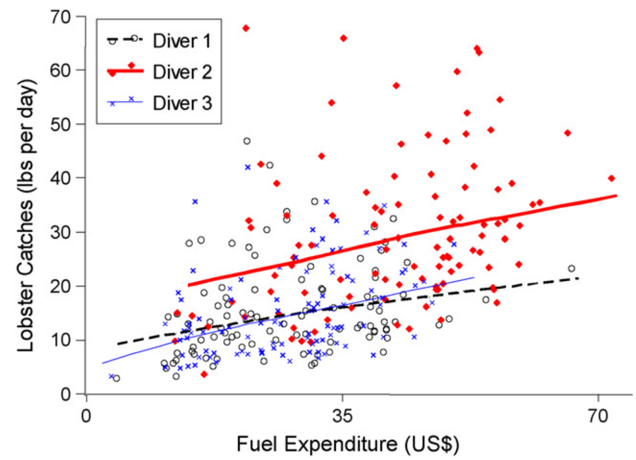


Fig. 6. Actual catches and fitted regressions of daily lobster catch against expenditure on fuel by three Corn Island divers between July and December 2002.

relationship found between fuel expenditure and catch for lobster divers predicts that there is an economic incentive for divers to focus on grounds farther from home. However, the costs associated with distance do not only involve fuel and other financial factors, but also non-monetary costs and incentives (Jennings et al., 2001). Bene and Tewfik (2001), for example, found that divers in the Turks and Caicos did not behave according to economic predictions due to social and technical factors like peer-pressure and diving ability. The qualitative results of this study suggest that the decision on how far to travel is affected by familiarity with grounds, conflicts with vessels from other islands, fuel cost, safety and opportunity costs of travel time. Fig. 7a shows a conceptual model of costs associated with distance for a Corn Island trap fisherman considering five of the factors discussed during the in-depth interviews and described by simple functional relationships with distance. The aggregate cost–distance function which incorporates all of these factors (Fig. 7b) is much more complicated than a simple fuel cost–catch rate relationship. Thus, appreciating how fishers' make spatial decisions requires a flexible and interdisciplinary approach that can cope with the complexity of factors which may be missed by solely reductionist economic modelling.

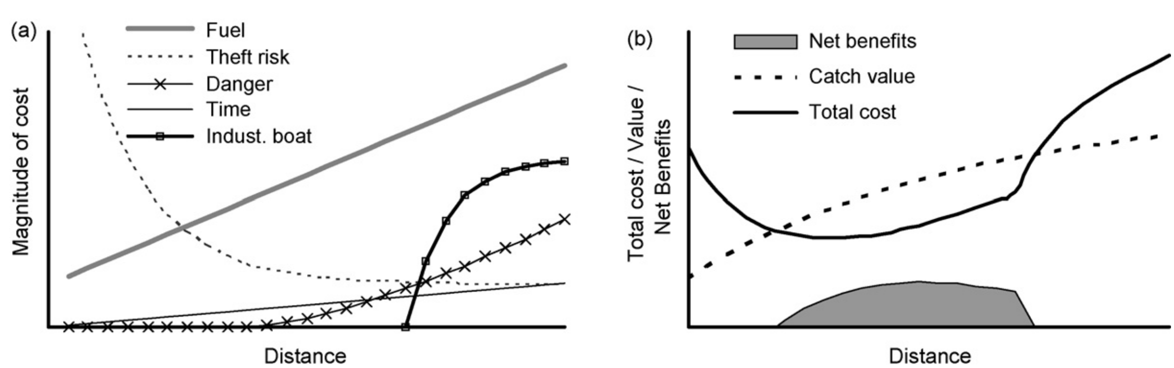


Fig. 7. (a) Conceptual diagram of the relationship between cost and distance for a lobster trap fisherman based on factors described in qualitative interviews and simple functional relationships. (b) Aggregate function of total costs with distance arrived at by summing costs in (a); asymptotically increasing relationship of catch value with distance and net benefits calculated as the difference between costs and revenue.

In addition, even if a straightforward fuel cost–catch trade-off did accurately represent fishers' decision making, it is questionable whether fishers could perceive generalised relationships like those in Fig. 6 given the variability experienced in catches and the impact of seasons and individual ground characteristics. In response to the question, "Do you catch more fish when you go further?" fishers typically said that sometimes catches were higher but that they could also be lower. Artisanal fishers elsewhere have been shown to be unable to discern spatial variation in catch rates in order to maximise their returns (Oostenbrugge et al., 2001; Pet-Soede et al., 2001). It was also mentioned on many occasions that grounds are fished cyclically, one diver claiming he used most of his grounds only once per year. In this scenario, although a generalised trend of greater catches at more distant grounds may be observed, it would be of little practical use for day-to-day decision making if divers selected grounds on the basis of those which had not been fished recently, irrespective of distance.

## 6. Conclusion

This study has used low-tech combined interview and GIS approaches to collect fishers' knowledge on the distribution of fishing effort around the Corn Islands and the related economics offering a cost-effective means to monitor fishing effort distribution and reconstruct past trends. Trap fishing effort had a highly aggregated dispersion while diving was regularly dispersed, perhaps because of the greater mobility and number of sites used by divers. Although fuel is a major part of fishers' costs, the range of the artisanal lobster fleet has, typically of many fisheries, expanded in recent years in response to higher CPUE at more distant sites, trap theft from nearshore grounds and new navigational technology. This expansion of range suggests that declines in lobster stocks may be more severe than perceived by declines in CPUE, and could impact the economic viability or profitability of operations. Spatial management measures, which are growing in popularity, should be considered in the light of existing spatial organisation of the fishery. Description of such organisation, can contribute to management planning by allowing spatial measures to incorporate existing patterns, and also help conventional stock assessment and management to take account of non-uniform fishing effort distribution. Understanding the factors underlying spatial effort distribution will help to predict the impact of MPAs on fishers and resources in terms of displacement of fishing effort, although there are likely to be a complex range of interacting factors that can only be appreciated by an interdisciplinary approach.

## Acknowledgements

Fishers, traders and residents of the Corn Islands are gratefully acknowledged for their assistance, cooperation and knowledge, especially Norma Dixon, Jose Manuel Alvarez and Melody Taylor. Clarence Gonzalez assisted with in depth interviews. Ulrika Gunnartz, Jessenia Bello, Karen Joseph and students from URACCAN conducted the bulk of the household survey. Ivan Weir and Bob Foster-Smith advised on research, John Bythell and Michael Daw provided advice on data analysis, Beatrice Crona assisted with preparation of figures. This study was part of 'Reefmap Nicaragua' funded by Rufford Small Grants, the Royal Geographical Society, Newcastle University and supported by MARENA. Tim Daw was supported by an NERC studentship and travel grant. The manuscript was substantially improved by the comments of two anonymous reviewers.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2007.09.027.

## References

Acheson, J.M., 1975. The lobster Fiefs: economic and ecological effects of territoriality in the Maine Lobster Industry. Hum. Ecol. 39, 183–207.

Adpesca, 2003. Annuario Pesquero y Acuicola de Nicaragua 2002. Administracion Nacional de Pesca y Acuicultura del Ministerio de Fomento, Industria y Comercio, Managua.

Ames, E.P., 2004. Atlantic cod stock structure in the Gulf of Maine. Fisheries 29, 10–28.

Aswani, S., 1998. Patterns of marine harvest effort in southwestern New Georgiam, Solomon Islands: resource management or optimal foraging? Ocean Coastal Manage. 40, 207–235.

Begon, M., Harper, J., Townsend, C., 1996. Ecology: Individuals, Populations and Communities. Blackwell Science, Oxford.

Begossi, A., 2001. Mapping spots: fishing areas or territories among islanders of the Atlantic Forest (Brazil). Reg. Env. Change 2, 1–12.

Bene, C., Tewfik, A., 2001. Fishing effort allocation and fishermen's decision making process in a multi-species small-scale fishery: analysis of the conch and lobster fishery in Turks and Caicos Islands. Hum. Ecol. 29, 157–186.

Booth, A.J., 2000. Incorporating the spatial component of fisheries data into stock assessment models. ICES J. Mar. Sci. 57, 858–865.

Caddy, J.F., Carocci, F., 1999. The spatial allocation of fishing intensity by port-based inshore fleets: a GIS application. ICES J. Mar. Sci. 56, 388–403.

de Castro, F., Begossi, A., 1995. Ecology of fishing on the Grande River (Brazil): technology and territorial rights. Fish. Res. 23, 361–373.

Devore, J., Peck, R., 1986. Statistics. West Publishing Co., St. Paul, Minnesota.

Eales, J., Wilen, J.E., 1986. An examination of fishing location choice in the pink shrimp fishery. Mar. Resour. Econ. 2, 331–351.

Gillis, D.M., 2003. Ideal free distributions in fleet dynamics: a behavioral perspective on vessel movement in fisheries analysis. Can. J. Zool.-Revue Canadienne De Zoologie 81, 177–187.

Gillis, D.M., Frank, K.T., 2001. Influence of environment and fleet dynamics on catch rates of eastern Scotian Shelf cod through the early 1980s. ICES J. Mar. Sci. 58, 61–69.

Gobert, B., Stanisière, J.Y., 1997. Spatial distribution of trap fishing effort in Martinique (West Indies). Aquat. Living Resour. 10, 93–100.

Hall, G.B., Close, C.H., 2007. Local knowledge assessment for a small-scale fishery using geographic information systems. Fish. Res. 83, 11–22.

Hilborn, R., Walters, C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman & Hall, New York.

Hilborn, R., Orensanz, J.M., Parma, A.M., 2005. Institutions, incentives and the future of fisheries. Philos. Trans. R. Soc. B-Biol. Sci. 360, 47–57.

Hume, D., Gunnartz, U., Daw, T., Badjeck, M.-C., Hunt, A., Velterop, R., Broadhurst, P., Zapata, Y., Segura, A., 2005. Reefmap Nicaragua 2003. Corn Islands and Pearl Cays Project Report, p. 150.

Hutchings, J., Myers, R., 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Can. J. Fish. Aquat. Sci. 51, 2126–2146.

Jennings, S., Alvsvag, J., Cotter, A., Ehrich, S., Greenstreet, S., Jarre-Teichmann, A., Mergardt, N., Rijnsdorp, A., Smedstad, O., 1999. Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity, and community structure. III. International trawling effort in the North Sea: an analysis of spatial and temporal trends. Fish. Res. 40, 125–134.

Jennings, S., Kaiser, M., Reynolds, J., 2001. Marine Fisheries Ecology. Blackwell Science Ltd., Oxford.

Koslow, J., Aiken, K., Auil, S., Clementson, A., 1994. Catch and effort analysis of the reef fisheries of Jamaica and Belize. Fish. Bull. 92, 737–747.

Levin, S., 1992. The problem of pattern and scale in ecology. Ecology 73, 1943–1967.

Maurstad, A., 2002. Fishing in murky waters—ethics and politics of research on fisher knowledge. Mar. Policy 26, 159–166.

Moustakas, A., Silvert, W., Dimitromanolakis, A., 2006. A spatially explicit learning model of migratory fish and fishers for evaluating closed areas. Ecol. Model. 192, 245–258.

Obura, D.O., 2001. Participatory monitoring of shallow tropical marine fisheries by artisanal fishers in Diani, Kenya. Bull. Mar. Sci. 69, 777–791.

Oostenbrugge, J.A.E., Densen, W.L.T., Machiels, M.A.M., 2001. Risk aversion in allocating fishing effort in a highly uncertain coastal fishery for pelagic fish, Moluccas, Indonesia. Can. J. Fish. Aquat. Sci. 58, 1683–1691.

Pet-Soede, C., Van Densen, W.L.T., Hiddink, J.G., Kuyl, S., Machiels, M.A.M., 2001. Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia. Fish. Manage. Ecol. 8, 15–36.

Rijnsdorp, A., Buijs, A., Storbeck, F., Visser, E., 1998. Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. ICES J. Mar. Sci. 55, 403–419.

Ryan, J.D., Miller, L.J., Zapata, Y., Downs, O., Chan, R., 1998. Great Corn Island, Nicaragua. In: Kjerfve, B. (Ed.), CARICOMP – Caribbean Coral Reef, Seagrass and Mangrove Sites. UNESCO, Paris, pp. 95–105.

Salas, S., Gaertner, D., 2004. The behavioural dynamics of fishers: management implications. Fish Fisheries 5, 153–167.

Schlager, E., Ostrom, E., 1992. Property-rights regimes and natural resources: a conceptual analysis. Land Economics 68, 249–262.

Sokal, R.R., Rohlf, F.J., 1981. Biometry: The Principles and Practice of Statistics in Biological Research. W.H. Freeman and Company, New York.

Walters, C., 2000. Impacts of dispersal, ecological interactions, and fishing effort dynamics on efficacy of marine protected areas: how large should protected areas be? Bull. Mar. Sci. 66, 745–757.

Walters, C., 2003. Folly and fantasy in the analysis of spatial catch rate data. Can. J. Fish. Aquat. Sci. 60, 1433–1436.

Wilen, J.E., 2004. Spatial management of fisheries. Mar. Resour. Econ. 19, 7–20.

Wilen, J.E., Smith, M.D., Lockwood, D., Botsford, L.W., 2002. Avoiding surprises: incorporating fisherman behaviour into management models. Bull. Mar. Sci. 70, 553–575.

Wroblewski, J., 2000. The colour of cod: fishers and scientists identify a local cod stock in Gilbert Bay, Southern Labrador. In: Neis, B., Felt, L. (Eds.), Finding Our Sea Legs: Linking Fishery People and their Knowledge with Science and Management. ISER, St. Johns, pp. 72–81.

Zuur, A.F., Ieno, E.N., Smith, G.M., 2007. Analysing Ecological Data. Springer-Verlang, New York.